



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
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MAR 05 1999

Mr. Carl F. Enson, P.E.
Chief, Engineering and
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U.S. Army Corps of Engineers
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Dear Mr. Enson:

Your letter of February 18, 1999, and its numerous enclosures raises both technical and procedural issues regarding the National Weather Service (NWS) estimate of Probable Maximum Precipitation (PMP) for the Cherry Creek Dam drainage provided by my office in July 1995. The technical issues are addressed in Enclosure 1, responding to Dr. Tomlinson's transmittal of August 19, 1997, which you included in your letter.

The procedural issues raised in your letter and its enclosures are concerned with the process followed by the NWS to review the Cherry Creek Dam study. Site-specific PMP studies produced by the NWS are assigned to a qualified PMP analyst and the completed study is reviewed by the technical manager who oversees the analyst. Once this review is completed, the NWS transmits the final study to the agency requesting the study. For this particular study, the PMP analyst was Douglas D. Fenn (assisted by Douglas R. Kluck). Louis C. Schreiner, author of Hydrometeorological Reports #51, #52, and #55A, was also consulted about the appropriateness of the procedures and he agreed. John L. Vogel was the technical manager; he completed his review on July 12, 1995, and the report was transmitted to the Corps of Engineers (COE) on July 13, 1995. Curriculum vitae of Messrs. Fenn, Kluck and, Vogel are provided as Enclosures 2, 3, and 4.

In consideration of the concerns expressed in your letter, I have asked for a further review of this study. John T. Riedel completed this review on February 25, 1999. Mr. Riedel's report and curriculum vitae are provided as Enclosures 5 and 6; he concluded (in part):

"Following a thorough review of the methodology applied in the site-specific study, I conclude that the approach is sound and within the current state of the practices of PMP analyses. Furthermore, a brief comparison of the results of the study with referenced studies and storms in the area gives no evidence to believe there are significant errors that would substantially change the results."



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In addition to the reviews of the site-specific PMP study for Cherry Creek Dam, the NWS PMP methodology has been the subject of a thorough scientific peer review by the National Research Council (Estimating Bounds on Extreme Precipitation Events--A Brief Assessment, National Academy Press, 1994, (Enclosure 7)) which concluded (in part):

" . . . there is no compelling argument for making immediate widespread changes in either PMP methodology or the NWS assessments of PMP, and the Committee recommends its continued use."

The NWS regional reports which form the basis for site-specific studies and estimates of PMP are also subject to a review process. The particular report of greatest interest to the Cherry Creek Dam is Probable Maximum Precipitation Estimates, United States Between Continental Divide and the 103rd Meridian, 1988, Hydrometeorological Report No. 55A. This report was reviewed in detail during 1986-88 by the "Interagency Hydro-meteorological Study Team" including representatives of the NWS, COE, Bureau of Reclamation, Soil Conservation Service (now renamed Natural Resources Conservation Service), and consultants.

In summary, both the methodology used by NWS to assess PMP and the NWS assessments have been subject to thorough reviews.

Sincerely,



Danny L. Fread
Director
Office of Hydrology

Enclosures 7

Enclosure 1

Discussion of "Peer Review of the NOAA PMP Study
for the
Cherry Creek Drainage in Colorado"

National Weather Service
Office of Hydrology

Introduction

In a letter to Dr. Danny Fread, Director of the Office of Hydrology, dated February 18, 1999, the U.S. Army Corps of Engineers asked the National Weather Service (NWS) Office of Hydrology (OH) to respond to a paper titled "Peer Review of the NOAA PMP Study for the Cherry Creek Drainage in Colorado." by Dr. E.M. Tomlinson. This response uses italics to set off Dr. Tomlinson's report from the NWS/OH response that follows in standard font. Items in the subject report which are in the nature of background information have no associated response.

Report and Response

*Peer Review of the NOAA PMP Study for the
Cherry Creek Drainage in Colorado*

*Edward M. Tomlinson, PhD
Applied Weather Associates*

Overview

Applied Weather Associates (AWA) has conducted a peer review of the approach taken and techniques used by NOAA PMP study, "Site-Specific PMP for the Cherry Creek Drainage in Colorado." The following issues were identified:

- 1. Use of a procedure developed for the eastern US where there are no significant orographic features without additional study justifying its use at the foothills of the Rocky Mountains*

The techniques developed for use east of the 105th Meridian are applied only to the non-orographic component of PMP in the Cherry Creek Basin in the 1995 NWS Site-Specific Study for the Cherry Creek Drainage in Colorado (1995 NWS Study).

2. *Use of the 100-year precipitation climatology for spatial variations of rainfall without establishing that the 100-year precipitation climatology was based on rainfall events (vs snowfall, a significant consideration in Colorado)*

Orographic factors based on rain-only records are indistinguishable from those based on mixed precipitation records in and around the Cherry Creek Drainage.

3. *Use of the assumption that extreme rainfall events over the Cherry Creek drainage is not significantly influenced by orography but increasing the PMP amounts by up to 14% due to orography*

A typical increase due to orographic effects for Cherry Creek is about 9 percent above the non-orographic PMP.

4. *Use of orographic among-storm factors to adjust non-orographic within-storm factors (a technical issue which could significantly increase the rainfall volume)*

The among-storm orographic adjustment factors (K-factors) at each point in the basin reflect the effect of topography on atmospheric forcing at the 100-year return-frequency level. Since all within-storm values of non-orographic PMP also reflect forcing at or above the 100-year return-frequency level, the orographic adjustment factors (K-factors) based on 100-year data are appropriate.

5. *The NOAA PMP amounts exceed the "maximized" largest storm which has occurred over or near the Cherry Creek drainage by over 60%.*

It is not clear how the cited "maximized" level was determined so the comparison cannot be verified against the NOAA PMP (1995 NWS Study).

6. *The NOAA PMP maximum point rainfall values exceed the 100-year return period precipitation in the Cherry Creek drainage by roughly a factor of seven. Other PMP studies in the western (sic) have factors ranging from 1.4 to 7.5, which places the results of this study in the extreme upper range of those found in other studies.*

The NOAA maximum point value of PMP storm precipitation is near the upper range mentioned.

The approach used by NOAA has, in general, lead (sic) to larger PMP values for the Cherry Creek drainage than would have resulted from a more detailed study.

It is not clear what results might be achieved by another, hypothetical "more detailed study."

The issues identified reflect on the reliability of the approach, assumptions and climatologies used as compared to the reliability that could be obtained from a more detailed study. Considering the importance of the results of a site-specific PMP study for the Cherry Creek drainage, the benefit in investing the time and effort required to enhance the reliability of the study appears to be justified.

Discussion

The US Army Corps of Engineers is considering modifications of the Cherry Creek Dam to provide safe passage of the Probable Maximum Flood (PMF). The rainfall associated with the computation of the PMF is provided by the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) in a report titled "Site-Specific PMP for The Cherry Creek Drainage in Colorado," dated July 12, 1995.

Applied Weather Associates (AWA) has been asked to review the site-specific study and provide comments on the approach taken and the applicability of the techniques used. The comments provided are general in nature since the specific details of some of the techniques, working papers and charts, and specific calculations of PMP values are not provided in the report.

The reviewer's overall impressions of the site-specific PMP study are concerns with the "site-specific" aspects of the approach used, and physical continuity and meaningfulness of the combination of assumptions and techniques used. Some of these concerns may be answered by knowing explicitly how the techniques used were applied and what climatologies were used and how. For example, the 100-year non-orographic precipitation is used but is not a published standard NOAA climatology product.

Portions of the 100-year non-orographic analysis are shown in Figure 9.1 of HMR 55A, "Probable Maximum Precipitation Estimates, United States Between the Continental Divide and the 103rd Meridian," (Hansen et al. 1988). The rest of the analysis is in work chart form. Traditionally, not all work charts used to prepare HMRs are published.

Approaches, techniques, and use of various climatologies in the site-specific study are discussed in this review. These discussions are meant to identify portions of the study where there are concerns related to the approach taken and techniques used. These concerns

focus on the appropriateness of the approach from an atmospheric physics perspective and continuity of assumptions within the study.

AWA sent a letter to the Corps of Engineers, dated May 16, 1997, identifying issues related with the data associated with and the analysis of the May 30-31, 1935, storm which occurred over the Cherry Creek drainage as well as over other locations along and east of the Palmer Divide. After reviewing the NOAA site-specific PMP study, these comments, although still appropriate for the 1935 storm analysis, are not directly relevant to the NOAA study since data and analyses of the 1935 storm were not used directly in the study. The comments do apply indirectly since among-storm PMP values used in the NOAA study do incorporate PMP values from HMR 55A which are derived in part from the 1935 storm.

The following comments apply to the NOAA Site-Specific PMP study for the Cherry Creek Drainage in Colorado, dated July 12, 1995:

The study uses concepts developed in HMR 52, "Application of Probable Maximum Precipitation Estimates-United States East of the 105th Meridian" (Hansen et al., 1982). NOAA justified using the HMR 52 concepts west of its previous western limit (the 105th meridian) by referencing Section 1.8 of HMR 55A (Hansen, et al, 1986).

The Cherry Creek Drainage is east of the 105th Meridian.

That section states that HMR 52 should be applied to PMP estimates between the 103rd meridian and the orographic separation line (OSL). However, it is also stated that incomplete consideration was given to storms within this region to permit use of HMR 52 procedures without additional study.

The full quotation from HMR 55A, Section 1.8, page 9 reads,

"HMR No. 52 should be applied to PMP estimates from the present study between the 103rd meridian and the orographic separation line. However, for those nonorographic regions that lie west of the 105th meridian, yet east of the orographic separation line, notably in eastern Montana and Wyoming, the application of HMR No. 52 procedures should be considered tentative. Incomplete consideration was given to storms with this region to permit use of HMR 52 procedures without additional study."

The area between the 103rd and 105th Meridians in Colorado is not included in this caution. Cherry Creek Drainage is east of the 105th Meridian, not in eastern Montana or Wyoming.

The OSL is defined in Section 3.2.1. of HMR 55A as being roughly 20 miles east of the base of the first upslopes of the Rocky Mountains as shown in Plate Vb from HMR 55A. As stated

in the NOAA study, "Virtually all of the Cherry Creek Drainage lies west of this line...". The NOAA study also states that "It was decided to overlook this limitation in this study...". The orographic influence of the Palmer Divide on several historic storms was evaluated. In discussing the 1935 storm, HMR 55A, Section 2.4.1.5 states that "The Kiowa center occurred in an orographic region known as the Palmer Ridge...This suggest that ...the Kiowa center may have been initiated and enhance by orography...." In the discussion of the 1965 storm, Section 2.4.1.7 of the same report states that there were "deep layers of conditionally unstable air that required only minimal lifting to release the instability. This initial lifting was readily available in Colorado as a result of diurnal heating and both terrain and frontal lifting." In summary,

- 1) HMR 52 was not originally intended to be applied west of the 105th meridian,*

There are two reasons HMR 52 cannot be applied indiscriminately west of the 105th Meridian: (1) there may be orographic effects west of the 105th Meridian and such effects are not accounted for in HMR 52, and (2) the developed within-storm relations could not be supplemented with additional non-orographic storms from farther west. However, the Cherry Creek Basin is east of the 105th Meridian and less than 16 miles into an orographic zone, as defined by the Orographic Separation Line (OSL) in HMR 55A. It was judged to be sufficiently close to the area from which within-storm relations were developed to warrant using HMR 52 techniques to develop the within-storm relations for the non-orographic component of PMP at Cherry Creek. The July 1995 site-specific study (1995 NWS Study) accounts separately through the K-factors for orographic effects not accounted for in HMR 52. Discussions of the application of HMR 52 between D. Fenn and D. Kluck, authors of the 1995 NWS Study, with J. L. Vogel, NWS Technical Manager, and with L. C. Schreiner, a co-author of HMR 52 and HMR 55A, established that the proposed use of HMR 52 techniques was acceptable in an area less than 16 miles west of the OSL (Orographic Separation Line).

- 2) HMR 55A states that HMR 52 could be applied as far west as the OSL but only after additional study,*

See discussion above.

- 3) the definition of the OSL in HMR 55A places most of the Cherry Creek drainage west of the OSL but the NOAA study overlooked this placement, and*

The relation between the location of the Cherry Creek Drainage and the OSL (Orographic Separation Line) was not overlooked.

4) analyses of historic extreme rainstorms over the Palmer Divide have identified orography as a significant factor.

While no source is given for the analyses cited by Dr. Tomlinson, HMR 55A and the **1995 NWS Study** recognized and quantified orographic effects.

The NOAA study justifies its use of HMR 52 for the Cherry Creek drainage by using non-orographic PMP depths provided in HMR 55A (Figure 8.7) along with depth-duration ratio maps (Section 10.3) which extend into the region just east of the OSL and depth-area-duration relations for non-orographic regions (Section 11.3.3).

HMR 52 techniques were originally developed to operate on the kinds of non-orographic information mentioned here.

Further discussion should be provided for this westward extrapolation of non-orographic relationships as suggested by the additional study recommendation as stated in HMR 55A cited above.

The requirement for future study cited in the last sentence of Section 15.3 in HMR 55A refers to the need to incorporate orographic effects into PMP estimates for areas not classified as completely non-orographic. Non-orographic relationships do not have to be abandoned in such areas; they may be used as long as they are applied only to the non-orographic component of PMP. Mr. Vogel and Mr. Schreiner supported the analysts' decision to extend appropriate non-orographic relationships, such as depth-duration relationships, to the Cherry Creek Drainage.

After deciding to overlook the placement of most of the Cherry Creek drainage within the orographic region in HMR 55A, the NOAA study devises techniques to define the interaction of the within-storm non-orographic depths with orography.

The NOAA study (**1995 NWS Study**) accounted for the location of the Cherry Creek Drainage with respect to the OSL (Orographic Separation Line).

This technique uses the PMP maps and the non-orographic index map from HMR 55A to obtain among-storm orographic factors (K-factors).

Agreed.

The use of K-factors is presented and discussed in NOAA Technical Memoranda NWS HYDRO 39 and 41. These are site-specific PMP studies for drainages in Massachusetts/Vermont and Kentucky.

It is not clear whether any objection is being raised here, but the reference to HYDRO 39 and 41 was to cite instances where similar procedures were used. These procedures were first used by the NWS in 1984 in Massachusetts/Vermont and in numerous studies since then, including the 1995 NWS Study. The other studies were done to define within-storm total PMP for orographic regions in the eastern United States. The technique used in Kentucky is described in Section 5.3.6 of the Manual for Estimation of Probable Maximum Precipitation (World Meteorological Organization, 1986). Section 5.3.6 describes how regional PMP studies can be used in a site-specific context.

The primary concern with this approach is the use of orographic factors to provide within-storm relationships for a non-orographic design storm using HMR 52 concepts. The NOAA study states that this is justified since the orographic factors range from 1.06 to 1.14 (i.e. increases in the non-orographic PMP depths of 6% to 14%).

This is a mis-interpretation of the study. The cited K-factors (1.06 to 1.14 at 24 hours) illustrate that the non-orographic component constitutes the major portion of total PMP storm precipitation. The techniques used would still be valid had larger K-factors been found.

These values are in the lower range of those found in regions classified as orographic in HMR 55A.

Higher K-factors are, indeed, found in other orographic regions in HMR 55A. But, as previously indicated, higher K-factors would not preclude usage of the methods employed in the 1995 NWS Study.

Additional concern arises from the use of among-storm orographic factors to modify the within-storm, non-orographic values to produce within-storm values of total PMP. Although the report does not provide the details of explicitly how this is accomplished, it appears that after extensive discussions on the importance of using within-storm relations for the design storm, among-storm values are in reality used.

It is important that within-storm, non-orographic precipitation be used for the study and that was definitely the case. What is important in adjusting within-storm non-orographic precipitation is that the orographic adjustment factors (K-factors) reflect the intensity level of the non-orographic precipitation. The K-factors derived from among-storm information

reflect an appropriate estimate of the effect of topography for the level of non-orographic forcing at each point in the drainage.

The NOAA study states that all other values needed for the application of HMR 52 are available for the Cherry Creek Drainage. The study states that "...all storms explicitly or implicitly transposable to the Cherry Creek Drainage contribute depth-area-duration values in the HMR 52 techniques.". It appears possible that large mesoscale convective complex storms which occurred over the mid-west and provided some of the largest rainfall depths in HMR 51, could directly influence the depth-area-duration values used for the Cherry Creek drainage.

The sentence quoted from the **1995 NWS Study** was intended to indicate that the HMR 52 technique uses averaged deviations from among-storm depth-area values to arrive at values of within-storm precipitation. The among-storm depth-area values from HMR 55A came from storms explicitly or implicitly transposable to the Cherry Creek Drainage. None of these were mid-western storms.

From the information given, it cannot be explicitly determined if this occurred but since storms implicitly transposable to Cherry Creek contribute to the depth-area-duration values, it appears possible. For example, the September 17-19, 1926, storm at Boyden, Iowa, was transpositioned westward to the 101st meridian. However it appears possible that the depth-area-duration curves associated with that storm could have directly influenced the design storm for the Cherry Creek drainage.

The depth-area relations averaged from 29 major non-orographic storms east of the 105th Meridian (including the Boyden, Iowa storm) provide a reliable indication of the relationship between within-storm and among-storm non-orographic rainfall in the Cherry Creek Drainage. This relationship is considered applicable for PMP storms between North Dakota and Florida and from Maine to Texas. The authors of the **1995 NWS Study** believe there are not enough non-orographic storm depth-area-duration data to justify unlimited extension of the within-storm/among-storm relationship from HMR 52 west of the 105th Meridian, but considered that its extension to the longitude of the Cherry Creek Drainage (which is east of the 105th Meridian) is reasonable.

Since the storm was not transpositionable west of the 101st meridian, it should have not direct influence on a design storm over the 105th meridian. It is not clear whether this storm or other storms over the eastern US used in the production of HMR 51 provided non-representative rainfall depths for the Cherry Creek drainage.

As stated above, the depth-area relations averaged from 29 major non-orographic storms east of the 105th Meridian (including the Boyden, Iowa storm) provide a reliable indication of the

relationship between within-storm and among-storm non-orographic rainfall to be found in the Cherry Creek Drainage. The among-storm depth-area values from HMR 55A came from storms explicitly or implicitly transposable to the Cherry Creek Drainage. None of these were mid-western storms.

The use of the GRASS software for computing rainfall depths over the watershed appears reasonable. Although there is some inconsistencies concerning the grid size used, even the most coarse of the grid sizes is appropriate.

The correct grid length used in the GRASS software was about 0.2875 miles or about 4670 grid points, not the 13,568 cited. The correct grid length was used in calculating PMP, and the incorrect citation had no effect on the average values of PMP.

There are several concerns related to the 100-year return level of precipitation. The first relates to the reliability of the analysis used. The NOAA precipitation map used was published in 1973 which suggest that the latest data used was probably about 1970. Considering that the Cherry Creek drainage has a low density of rainfall observations together with a relatively short period of record in 1970, the analysis should be updated using the additional 25+ years of data currently available (Telecom, Nolan Doesken, Colorado Climate Center, Aug 15, 1997).

NOAA Atlas 2, "Precipitation Frequency Atlas of the Western United States" (1973), until superseded, remains the Federal standard for precipitation frequencies for hydrologic design for the western United States. An update to this standard would be a significant project.

Additionally, the 1973 analysis did not separate precipitation by phase, i.e. snow vs rainfall.

This statement is not true. NOAA Atlas 2, vol.III, Colorado (1973) contains separate values based on mixed precipitation (all-season) records (Figures 20 to 31) and on May-October precipitation (Figures 32 to 43).

Hence, for locations such as the Palmer Divide, the 100-year precipitation amount and geographic pattern could have been produced by rainfall observations, snowfall observations, or a combination of rainfall at some station and snowfall at an adjacent station.

NOAA Atlas 2, vol.III, Colorado (1973), Figure 31 (100-year, 24-hour precipitation, all-season) and Figure 43 (100-year, 24-hour precipitation, May-October) in and around Cherry Creek indicate that the orographic factors derived from May-October records are essentially the same as those derived from mixed precipitation (all-season).

The important point here is if the 100-year precipitation pattern on the north slope of the Palmer Divide is derived from extreme snowfall events, it is inappropriate for use in evaluating extreme rainfall patterns.

The orographic factors, based on NOAA Atlas 2, used in the **1995 NWS Study** are reliable indicators of the effects of topography, including the Palmer Divide, on the non-orographic forcing in a PMP storm in the Cherry Creek Drainage.

If the PMP storm for the Cherry Creek drainage is associated with generally southeasterly wind flows containing high levels of moisture from the Gulf of Mexico (as has been associated with historic large rainfall events along the Palmer Ridge), then orographic enhancement suggested by the 100-year precipitation pattern may not be appropriate.

Since the May-October records most likely associated with the southeasterly flow mentioned produce orographic ratios indistinguishable from those associated with all-season precipitation records, the orographic adjustment factors (K-factors) used in the **1995 NWS Study** are regarded as reliable.

Hence it is important to compare the type of PMP storm and its associated inflow winds with the type of 100-year storm and its associated inflow winds.

The inflow directions associated with the storms fixing the 100-year level of precipitation are much like the inflow direction likely in a PMP storm. The derived orographic factors (K-factors) in the **1995 NWS Study** associated with this flow are of the proper magnitude.

Mr. Doesken will attempt to determine from the records at the Colorado Climate Center what precipitation records contributed to the establishment of the 100-year precipitation pattern for the north slope of the Palmer Divide (Telecom, Aug 15, 1997). The NOAA study used the level of the 100-year non-orographic precipitation in its calculations.

Charts of the 100-year level of non-orographic precipitation (internal working documents) were used to help set values of orographic influence in the regional study, HMR 55A. The same values were used in **1995 NWS Study**.

This is not a published climatology.

The charts of the 100-year level of non-orographic precipitation were not published, but their derivation is discussed in HMR 55 A (see Section 9.2). It was an editorial decision not to publish all the work charts in HMR 55A.

What appears to have been used were values perceived to be non-orographic from locations east of Cherry Creek. These perceived values need to be fully justified as being appropriate for use over the Cherry Creek drainage since they were derived from a geographically dissimilar region.

Values of the 100-year level of non-orographic precipitation, both east and west of the Cherry Creek Drainage were used to establish its value in the Cherry Creek Drainage

The PMP values derived from the NOAA study were compared with the 1935 storm. While the maximum point value "observed" exceeded the maximum point value from the study, the study PMP value for the area of the Cherry Creek drainage exceeded the 1935 storm by about a factor of 2. The conclusion stated in the study is that it is reasonable to believe that the 1935 storm maximized near 10 sq mi or less. Since there is a significant difference in the within-storm relationships between the design PMP storm and the 1935 storm, was the 1935 storm atypical for the Cherry Creek drainage location or were the within-storm relations used for the PMP design storm derived from storms which are not appropriate for use over the Cherry Creek drainage location?

The 1935 storm, centered just a few miles east of the Cherry Creek Drainage, is associated with synoptic weather conditions typical of the region. A PMP storm for the Cherry Creek Drainage would likely share many of these synoptic characteristics. However, storms with the same synoptic characteristics can have different within-storm depth-area-duration characteristics. If the PMP storm has depth-area-duration characteristics different from one particular storm with typical synoptic characteristics, the PMP storm does not have to have "atypical" synoptic characteristics. To re-iterate, storms with the same synoptic characteristics can have different depth-area-duration characteristics.

If the observed rainfall analysis of this storm is "maximized" using standard procedures and the maximization factor of 1.22 presented in HMR 51, the rainfall volume of the NOAA design storm exceeds the maximized 1935 storm rainfall volume by over 60%.

HMR 51(1978) lists a maximization factor of 1.22 for the storm at Hale, Colorado, not for Cherry Creek, Colorado. (Hale, Colorado is in eastern Colorado within a few miles of the Kansas border). The maximization factor used for the Cherry Creek storm in HMR55A is 1.5. Using the factor of 1.5 and the 1985 Bureau of Reclamation storm study (Study MR3-28A-Zone A - May 30-31, 1935 Storm Rainfall Centers N.E. of Colorado Springs, Co - Cherry Creek Storm), PMP amount exceedances range from 13 percent at 6 hours to 45 percent at 24 hours.

The NOAA study states that "The maximum point values at 6- and 24-hours from this study exceed the largest 100-year return period precipitation in the Cherry Creek Drainage

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by roughly seven times." For comparison, data provided in Section 5.5 of HMR 49 indicate that the PMP values provided in that study for the Colorado River and Great Basin Drainages range from 1.4 to 5.9 times the 100-year point rainfall values. Table 13.1 from HMR 57 for the Pacific northwest states present maximum values that range from 3.2 to 7.5 times the 100-year precipitation values. The ratio of PMP to 100-year values for the site-specific Cherry Creek drainage PMP study is decidedly in the extreme upper range of those found in other PMP studies for the western US.

According to NOAA Technical Report NWS 25 (1980), "Comparison of Generalized Estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls," the ratios of 10-mi² PMP to the 100-year level in the HMR 49 (1977), "Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages" area at 6 hours, range from less than 3 times to 8 times or slightly above; at 24 hours, the range is from less than 3 times to 6 times or slightly above. The values cited by Dr. Tomlinson are from Table 13.1 of HMR 57, and are for 1 and 72 hours, rather than for 6 and 24 hours as reported in the 1995 NWS Study. The ratios cited by Dr. Tomlinson are for storms west of the Continental Divide, which are decidedly different from storms east of the Continental Divide. The values for the Cherry Creek Drainage are in the upper range of other ratios found in the western United States.

In order to provide an estimation of the role of the orography associated with the Palmer Divide on the initiation and location of extreme storm events, AWA is working with Dr. Jan Paegle with the Meteorology Department at the University of Utah. Case studies are being run using a numerical mesoscale meteorological model to estimate the influence of the terrain upslope and downslope of the Palmer Divide on the initiation of storm activity and the location of the resulting rainfall with respect to the ridgeline. Although the detail involved with these case studies cannot quantify rainfall amounts and exact locations, they should provide some quantification of the orographic influence of the Palmer Divide on extreme rainfall events.

NWS will carefully review the results of Dr. Jan Paegle's studies when published for their applicability in a PMP context.

Conclusion

These comments are provided to express concerns over various approaches, assumptions and climatologies used in the site-specific PMP study provided by NOAA for the Cherry Creek drainage. The approach used by NOAA has, in general, lead to larger PMP values for the Cherry Creek drainage than would have resulted from a more detailed study. The issues identified reflect on the reliability of the approach, assumptions and climatologies used as compared to the reliability that could be obtained from a more detailed study. Concerning the importance of the results of a site-specific PMP study for the Cherry Creek drainage, the benefit in investing the time and effort required to enhance the reliability of the study appears to be justified.

It is not clear what results might be achieved by another, hypothetical "more detailed study."

Enclosure 2

Douglas D. Fenn

Doug Fenn is a meteorologist and probable maximum precipitation (PMP) expert with the Hydrometeorological Design Studies Center (formerly the Hydrometeorological Branch) of the National Weather Service (NWS) Office of Hydrology in Silver Spring, MD. He began as a PMP analyst in 1981 and developed his skills and knowledge under the tutelage of NWS PMP experts in the Hydrometeorological Branch. He has co-authored five PMP reports, the latest being *Hydrometeorological Report No. 59, Probable Maximum Precipitation for California* in 1999. He has also authored or co-authored eight site-specific PMP studies. Prior to joining the NWS Mr. Fenn was employed as a research meteorologist for General Electric in Beltsville, MD from 1975-1980. He was a meteorologist for the Environmental Technical Applications Center in Washington, DC from 1968-1975. He also worked as a meteorologist for the Franklin Institute in Philadelphia. For four years he served as a US Air Force meteorologist at the Severe Weather Warning Center, Kansas City, MO. Mr. Fenn received a B.A. in Philosophy from Hobart College. He also has taken graduate courses in Meteorology at New York University and in Physics at Columbia University.

PMP Reports

Hydrometeorological Report No. 59 - *Probable Maximum Precipitation for California*, February 1999.

Hydrometeorological Report No. 58 - *Probable Maximum Precipitation for California, Calculation Procedures*, October 1998.

Hydrometeorological Report No. 57 - *Probable Maximum Precipitation - Pacific Northwest States*, October 1994.

Hydrometeorological Report No. 55A - *Probable Maximum Precipitation Estimates - United States Between the Continental Divide and the 103rd Meridian*, June 1988.

Hydrometeorological Report No. 56 - *Probable Maximum and TVA Precipitation Estimates with Areal Distribution for Tennessee River Drainages Less Than 3,000 Mi² in Area*, October 1986.

Published Site-Specific Studies

NOAA Technical Memorandum NWS Hydro 41 - *Probable Maximum Precipitation Estimates for the Drainage above Dewey Dam, Johns Creek, Kentucky*, August 1985.

NOAA Technical Memorandum NWS Hydro 39 - *Probable Maximum Precipitation for the Upper Deerfield River Drainage Massachusetts/Vermont*, June 1984.

Unpublished Site-Specific Studies

Cold Brook Watershed, SD, October 1996

Mussers Dam, PA, August 1996

Cherry Creek Drainage, CO, July 1995

Savage River Dam, MD, February 1994

Roxbury Dam, PA, November 1993

Jennings-Randolph Drainage, MD, June 1992

Enclosure 3

Douglas R. Kluck

Douglas R. Kluck is currently a forecast meteorologist and serves as the hydrological focal point with the National Weather Service Forecast Office in Hastings, NE. From 1992-1998 Mr. Kluck was a meteorologist for the Hydrometeorological Design Studies Center of the National Weather Service (NWS) Office of Hydrology in Silver Spring, MD focusing on probable maximum precipitation (PMP) studies. He was the co-author of two PMP reports, the latest being *Hydrometeorological Report No. 59, Probable Maximum Precipitation for California* in 1999. Mr. Kluck was also co-author of three site-specific PMP studies. He was on a Board of Consultants for the Federal Energy Regulatory Commission for a PMP study for Lake Chelan, WA in 1998. Prior to joining the NWS Mr. Kluck was employed as a research meteorologist for North American Weather Consultants in Salt Lake City, UT from 1991-1992. Mr. Kluck received a B.A. in Geology and a M.A. in Geography from the University of Nebraska.

PMP Reports

Hydrometeorological Report No. 59 - *Probable Maximum Precipitation for California*, February 1999.

Hydrometeorological Report No. 58 - *Probable Maximum Precipitation for California, Calculation Procedures*, October 1998.

Site-Specific Studies

Cold Brook Watershed, SD, October 1996

Mussers Dam, PA, August 1996

Cherry Creek Drainage, CO, July 1995

Enclosure 4

John L. Vogel

John L. Vogel is currently Director of the National Weather Service Training Center in Kansas City, MO. From 1988-1996 he was Chief of the Hydrometeorology Branch (precursor of the Hydrometeorological Design Studies Center) of the National Weather Service (NWS) Office of Hydrology in Silver Spring, MD. As Branch Chief he directed probable maximum precipitation (PMP) and precipitation frequency investigations. He was the supervisor and gave direction for the PMP studies in the Pacific Northwest States and California, and was co-author of three regional PMP studies. He also supervised six site-specific PMP studies performed by the NWS. He was a reviewer for the Electric Power Research Institute (EPRI) PMP study for Wisconsin and Michigan - General Studies and Workbook and User Guide. He used new techniques and data sources for PMP, for example, satellite and radar studies. He also served as a reviewer for the Federal Energy Regulatory Commission for PMP studies for North Carolina, the Pacific Northwest, Michigan, and Wisconsin, and for the Atmospheric Environment Service of Canada for PMP studies for British Columbia. Under the sponsorship of EPRI and others, Mr. Vogel taught classes on PMP techniques and research to Federal, State, and Local agency employees. Mr. Vogel directed and supervised precipitation frequency studies for Pennsylvania and West Virginia, the Southwest United States, and Texas, and initiated a study for the Ohio River Valley. Mr. Vogel delivered at least 25 papers on PMP and precipitation frequency to professional organizations including the American Society for Civil Engineers, the Association of State Dam Safety Officials, and the American Meteorological Society.

Prior to joining the NWS Mr. Vogel worked for the Illinois State Water Survey (Survey) in Champaign, IL from 1972-1988. While at the Survey he fulfilled many varied positions. He was Chief of the Climate Information Center from 1982-1988 and Director and Regional Climatologist for the North Central Regional Climate Center from 1983-1987. During his 17-year tenure at the Survey he was a research meteorologist and supervisor for research in the following areas: inadvertent weather modification (cooling lakes and urban environments), numerous climatic analysis of precipitation data over dense raingauge networks in Illinois and the central United States, radar-rainfall relations for real time use, precipitation frequency values for North Central Illinois, convective storm effects on lakes using satellite data, various synoptic weather relations for urban rainstorms, and urban networks in Chicago. Mr. Vogel has a B.S. and M.S. in Meteorology from Saint Louis University.

PMP Reports

Hydrometeorological Report No. 59 - *Probable Maximum Precipitation for California*, February 1999.

Hydrometeorological Report No. 58 - *Probable Maximum Precipitation for California, Calculation Procedures*, October 1998.

Hydrometeorological Report No. 57 - *Probable Maximum Precipitation - Pacific Northwest States*, October 1994.

Enclosure 5

John T. Riedel
Hydrometeorological Consultant
February 24, 1999

Review of Site-Specific PMP Estimate (1995) for Cherry Creek,
Colorado

Background

The center of the Cherry Creek drainage above Cherry Creek Dam, an area of 386 mi², is near latitude 39° 18' and longitude 104° 48'. It is approximately 100 miles long, extending almost the entire distance between Denver and Colorado Springs, Colorado. The site-specific PMP study (1) was completed by the National Weather Service on July 13, 1995.

In addition to the site-specific study, three other NWS reports are of interest: This drainage falls within the region giving estimates of probable maximum precipitation (PMP) that are given in Hydrometeorological Report (HMR) #51 (2). The report covers the U.S. east of the 105th meridian. However, it shows a stippled region between longitude 103° and 105° where the estimated PMP may need further evaluation because of terrain effects. Also of interest to the subject drainage is HMR 52 (3). It gives guidance on application of HMR 51 PMP to specific drainage areas. The guidance covers such subjects as orientation and shape of PMP storm isohyets, whether PMP values can be applied to smaller areas within a subject drainage and the temporal distribution of PMP. Also of interest is HMR #55A (4). Estimated PMP values are given for the region between the Continental Divide and the 103rd meridian--within which the Cherry Creek drainage lies. It (HMR 55A) supercedes HMR 51 for this region.

The given "Statement of Work" breaks down the review into 4 tasks. These tasks will be subheadings a. to d. in the following review:

a. *Relevancy of HMR 55A to the site-specific estimates of PMP.*

Except for adopted modifications, the estimates are basically from HMR 55A. This includes obtaining total PMP values for 1, 6, 24, and 72 hours from Plates I to IV of that report and using a depth-area relation of HMR 55A for the specified region of the drainage.

b. Accuracy of the site-specific estimates.

The accuracy of a PMP estimate is difficult to define. One can make comparisons with estimates from other methods and judge whether differences are realistic. Several simple calculations were made for comparison. Values computed directly from HMR 51 averaged 90% of those in this site-specific study. The Cherry Creek storm rainfall of May 30-31, 1935 (which had a major center quite close to the problem drainage), when adjusted for maximum moisture (1.48) gave values for 6 and 12 hours within a few percents of the HMR 51 values. HMR 55A values are from 15% to 20% greater than those of the study being reviewed. These comparisons show that the site-specific estimates are in the proper general range. This study has more details than many site-specific studies. For example, maps are provided (Figures 2 to 5 of the site-specific study) which incorporate the orographic intensification, and then give the depths at 4670 points in and surrounding the drainage. An analysis of these depths give the final isohyetal maps.

c. Applicability of HMR 55A to the drainage and methodology adopted in the site-specific study.

The applicability of HMR 55A is discussed in Section a. This review has not thus far covered the application of techniques of HMR 52. As stated, that report covers this drainage. The storm isohyets produced are based on "within-basin" depth-area relations to obtain depths for the drainage size and isohyets for the 4 durations. This site-specific study is unusually thorough--most site-specific studies do not give such details.

The orographic factors involved in this study were computed from comparison of total PMP to non-orographic PMP. They give the best estimate of orographic PMP factors that are available. Studies of these factors have never been made with as much detail as in this study. Site-specific estimates developed from HMR 55A are based on the best available background.

d. Recommendation for revisions to methods or results.

1. Following a thorough review of the methodology applied in the site-specific study, I conclude that the approach is sound and within the current state of the practices of PMP analyses. Furthermore, a brief comparison of the results of the study with referenced studies and storms in the area gives no evidence to believe there are significant errors that would substantially change the results.

2. A point of concern is that the text is written for the understanding of fellow hydrometeorologists who are familiar with the available data and its analyses and the published estimates. I would not expect hydrologists to understand it. I recommend an outline such as given in HMR 55A, pages 213 and 214 be prepared, but with the additional steps taken for the modifications for the drainage and the adaptation of HMR 52 methods.

References

1. Site-Specific Probable Maximum Precipitation for the Cherry Creek Drainage in Colorado, U.S. National Weather Service, Report for U.S. Army Corps of Engineers, HQDA (DAEN-CWH-Y), July 12, 1995.
2. Hydrometeorological Report #51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, 1978.
3. Hydrometeorological Report #52, Application of Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, 1982.
4. Hydrometeorological Report #55A, Probable Maximum Precipitation Estimates, United States Between the Continental Divide and the 103rd Meridian, 1998

Enclosure 6

John T. Riedel

John T. Riedel is a hydrometeorological consultant with a long history of probable maximum precipitation (PMP) experience. He was a PMP consultant for Morrison-Knudsen Engineers Inc. in San Francisco, CA from 1995-1996. He also was a PMP consultant for the Phillippines and Malaysia in 1993. Mr. Riedel was vice president and principal hydrometeorologist for Wang, Riedel & Associates, Inc. in Chicago, IL from 1988-1993. While vice president of Wang, Riedel & Associates he performed hydrometeorological analyses leading to the estimation of site-specific PMP and spatial and time distribution of PMP. He also estimated seasonal variation of PMP, and applied generalized PMP estimates for specific sites, as well as reviewing such PMP studies. Mr. Riedel has been a hydrometeorological consultant for international organizations such as the World Meteorological Organization and the World Bank (1980-1986), government organizations such as the U.S. Academy of Sciences (1985) and major engineer firms such as Harza Engineering Company in Chicago, IL (1982-1987) and Morrison-Knudsen Engineers, Inc. in San Francisco, CA (1987). As a consultant Mr. Riedel worked on many PMP studies including the Coosa and Tallapoosa River Basins in Alabama and Georgia, a site-specific study for the Jackson River Basin in Virginia, a study of the Itaipu project in Brazil, and a review of the Bakun study in Sarawak, Malaysia. Before Mr. Riedel became a private consultant, he was employed as a meteorologist focusing on PMP studies for the National Weather Service Office of Hydrology in Silver Spring, MD from 1947-1980. From 1967-1980 he was Chief of the Hydrometeorological Branch. During the 34 years he worked for the NWS he co-authored 26 PMP reports and 9 reports on other precipitation analysis studies. Mr. Riedel received a B.S. in Meteorology from the University of California at Los Angeles and has taken graduate courses at the University of Maryland and the Department of Agriculture Graduate School.